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A PROGRAM FOR BREEDING INDUSTRIAL POTATO VARIETIES[1]

G. V. C. Houghland, R. V. Akeley, and A. E. Kehr[2]

Introduction

In several European countries certain potato varieties are grown specifically for industrial purposes. In Germany, industrial potatoes, or "fabrik kartoffel," constitute about 7% of the potato crop, or more than 50 million bushels. In this country, however, the potatoes used for industrial purposes consist of culls and surplus potatoes from the tablestock crop. In the past, these sources of supply have been fairly adequate but as developments in potato processing continue, the supply of potatoes for industrial purposes tends to decrease and become inadequate. One of the principal factors in this change is the relatively recent development of a process for making dehydrated potato flakes.

While the sources of potatoes available for industrial purposes are becoming more limited because of increased use in processing. Research and development in the manufacturing processes for potato starch and flour, according to Treadway (5) are advancing, and the demand for these products is increasing. The shrinking supply of raw material and the increasing demand for the manufactured products tend to make the need for an industrial potato variety, grown solely for industrial purposes, more urgent.

Materials and Methods

Specifications for an industrial potato variety, from the industry viewpoint, should include high starch and dry matter content and good keeping quality. From the grower's standpoint it should be capable of economic production of high yields of starch per acre under intensive cultural practices and should be medium late in maturity and resistant to blight and other major potato diseases. A breeding program specifically aimed at producing such a potato variety was first initiated in this country in 1959, when a project for this purposes was commenced by the United States Department of Agriculture at Beltsville, Maryland. This project is designed to attack the problem from four approaches: breeding, selection by seed germination in sucrose, selection by chemical analysis, and field selection of plants for maximum radiant absorption.

Breeding program: In the breeding program, lines with high starch and dry matter content are being grown in the greenhouse and selfed wherever possible to obtain true seed. Individuals that cannot be selfed are sib-crossed or crossed with other high-starch receptive parents. By this procedure it is hoped to get more uniform production of high starch and dry matter and increase these characteristics to the highest level possible for potatoes.

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[1]Accepted for publication April 13, 1961.

[2]Vegetables and Ornamentals Research Branch, Crops Research Division, Agricultural Research Service, United States Department of Agriculture, Beltsville, Maryland.

Seed germination in sucrose: The batches of seed obtained in the breeding program were divided into two lots; one lot was germinated in solutions of sucrose and the other in water. The object of the sucrose germination is to subject the seed to osmotic pressure just high enough to permit a 5 or 6% germination. This method, devised to segregate lines more vigorous and possessing potentialities for enhanced resistance to drought, cold, and salinity, has been used in Germany with reported success on barley, wheat, beans, buckwheat, and tomatoes. Fryxell (2) has suggested a broad application of the method to segregating material, which prompted its use in the present program. It has been found that the seed of potato varieties and seedlings differ in their reaction to this treatment, requiring from 2 to 10% sucrose solutions to suppress germination of the viable seed.

The small seedling plants obtained after germination in the sucrose solutions and in water were grown in 3-inch pots in the greenhouse to produce seedling tubers. These were later planted in the field, and at harvest, tuber selections were made from each hill.

Chemical analysis: During the following winter the tubers selected from each hill produced from the sucrose- and water-germinated seed were analyzed for starch and dry matter. Starch was determined by a hydrolysis-polariscopic method (3) and dry matter by loss of weight after drying. So far over 500 determinations of these types have been made and the results are summarized in Table 1.

Among the five family lines compared for the effect of sucrose germination, only one seedling line so far has shown a significant increase in percent of starch apparently due to the sucrose germination treatment. All the differences in the average percentages of starch from sucrose- and water-germinated seed shown in Table 1 were small. If, however, the sucrose treatment is effective these differences should increase and probably become significant as breeding and selection continue.

Field selection of plants for maximum radiant absorption: Potatoes produce, in a temperate climate, more energy food per unit of soil area occupied than any other vegetable crop. Unquestionably most of the energy for this large production is derived directly from the sun. It is evident, therefore, that the morphology of the potato plant must play a highly important part in determining the amount of radiant energy absorbed and energy food produced. In a recent study of the physiology of photosynthesis in higher plants, Went (6) brings out the striking fact that when leaves are packed too closely or held at too small an angle to the light source, the efficiency of total light utilization by the plant drops sharply. This effect of leaf angle apparently has an important bearing on the ability of potato varieties to produce under intensive culture. Houghland and Akeley (4) have shown that the varieties Saco, Kennebec, and Katahdin, all of which have "open" type of vine growth, with leaves held at an acute angle, were better adapted to intensive culture than Merrimack. Merrimack has an "umbrella" type of vine growth with leaves held more nearly perpendicular to the source of light, and this causes more shading of the lower leaves.

TABLE 1.—*Average percentages of starch in potatoes grown in 1960 from seedling tubers originating from seed sprouted in sucrose and in water in 1959.*

Pedigree number	Parentage	Seed treatment	Seedlings sampled	Average starch content	Difference in starch between sucrose and water treatment
			No.	per cent	per cent
B 1637	Katahdin selfed	7% Sucrose	11	14.14	+0.08 ± 0.91
B 1637	Katahdin selfed	Water	11	14.06	---
B 1638	Merrimack selfed	7% Sucrose	12	14.48	*—1.37 ± 0.93
B 1638	Merrimack selfed	Water	12	15.85	---
I 58160	Redskin x B 606-3	2% Sucrose	10	15.69	+0.70 ± 0.78
I 58160	Redskin x B 606-3	Water	10	14.99	---
I 5804	I 781-7 x 606-3	4% Sucrose	23	16.16	**+1.46 ± 0.467
I 5804	I 781-7 x 606-3	7% Sucrose	23	15.53	+0.83 ± 0.467
I 5804	I 781-7 x 606-3	Water	23	14.70	---
I 5817	I 801-10 x B 3511-17	10% Sucrose	24	14.07	+1.21 ± 1.98
I 5817	I 801-10 x B 3511-17	Water	24	12.86	---

*Difference in favor of germination in water.
**Significant at 1% point; all others not significant.

From an analysis of work done on light utilization by tomatoes and other plants, Went (6) concludes that light with an average intensity above 1000 foot candles at the leaf surface is largely wasted. He states further that when the noonday light intensity on a sunny day is about 10,000 foot candles, most of the sunlight is wasted. Went (6) also points out that leaf hairs are strongly reflective and therefore tend to reflect excess light so that surrounding leaves, especially lower ones, are benefited. Corrugated leaf surface, he states, is also another means by which excess light intensity can be reflected so that a larger proportion of the total light can be used by the plant.

From these facts it would seem that the ideal potato plant for maximum radiant-energy utilization should be one having upright, open-type vine growth with the leaves held at an acute angle with abundant leaf pubescence and currugated leaf surfaces. It is interesting to note that the European varieties Industrie, President, and Up-to-Date and other varieties which are used for industrial purposes all have tall, upright, open-type vine growth and dull corrugated leaflets. Accordingly, selections for such types are being made in the field from among the seedling progenies and these are staked and harvested separately so that their tubers can be analyzed for starch and dry matter. These types will be maintained as separate breeding lines possessing known propensities for starch and dry matter production and ultimately increased for testing under intensive culture as outlined by Houghland and Akeley (4).

In 1941 and 1942, Akeley and Stevenson (1) compared the starch-producing abilities of 16 high-starch producing European varieties, when grown in this country, with 13 American varieties. Green Mountain produced more starch per acre than any other variety in the trial. Today we have one or more new varieties that surpass Green Mountain in percent

of starch and significantly outyield this older variety. These are being used to advantage in the program designed to produce an outstanding industrial potato.

Summary

A program for breeding industrial potato varieties has been described in detail. Starch analyses and dry matter determinations, germination of seed in sucrose solutions, and field selections of plants capable of maximum radiant absorption with "open" type vine growth, corrugated leaflets, and pubescence all are being employed in the breeding and selection of seedlings possessing outstanding potentialities for high starch and dry matter production. Promising seedlings are being increased and finally will be field-tested for economic production of starch per acre under intensive cultural conditions.

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THE INFLUENCE OF IRRIGATION REGIME ON YIELD AND QUALITY OF POTATO TUBERS AND NUTRITIONAL STATUS OF PLANTS[1]

JAY L. HADDOCK[2]

Yields of potatoes in the United States have doubled during the past 15 years. Nevertheless, alert growers are eagerly seeking information on cultural practices which favorably influence yield. Research workers are continuously searching for a better understanding of "the mystery of growth". In the past, workers dealing with nutrient status of the plant as related to potato production have been primarily concerned wtih the influence of fertilizer on the yield of potato tubers (3, 4, 5, 10, 11, 12, 13, 14, 16, 19). Relatively little work has been reported on the influence of irrigation practices on yield and quality of the potato crop and particularly as these factors are related to nutrient composition. Since more than 20% of the potatoes consumed today is commercially processed and sold in a form represented by chips and frozen French fries, increasing attention is being focused upon factors affecting cooking quality.

Hampton et al. (7) report that the economic need for supplemental irrigation of potatoes in certain Long Island, New York production areas has been well demonstated by the recent rapid increase of irrigated acreage. These investigators show that 1.5 inches of water per week (rainfall plus irrigation) gave best yields of potatoes. Harris (8) and Harris and Pittman (9), among others, early demonstrated the importance of good irrigation practice on yield of potato tubers in the arid West. Thiessen (18) observed that mealy potato varieties were relatively less mealy when grown on irrigated rather than unirrigated land in Wyoming.

While the literature contains numerous suggestions for appraising the nutritional status of potato plants, no one method is generally accepted. Kittams (12) proposes the use of "critical levels" and concludes that the fourth or fifth potato leaf blade from the top of the plant should contain at least 6% nitrogen, 0.4% phosphorus, and 4.5% potassium for plants 8 to 10 inches in height.

The Potash News Letter for Western Territory No. 26, December, 1958 presents the potato leaf petiole nutrient classification chart used in California. Plant samples in late seasons (90 days or more from planting) are considered to be well nourished when the acetic acid soluble nitrate-nitrogen, phosphorus, and potassium concentration in recently matured leaf petioles are above 5,000, 1,000, and 60,000 ppm respectively.

MATERIALS AND METHODS

Two methods of irrigation, sprinkle (S) and furrow (F), with four soil moisture conditions superimposed on each method (available soil

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moisture remaining in the root zone allowed to approximate 90 (W_4), 70 (W_3), 40 (W_2), and 20 (W_1)% between irrigations) were studied.

The soil used in this study was a well-drained calcareous Millville loam with a pH near 8 and a calcium carbonate equivalent of about 50%. The crop rotation consisted of canning peas, alfalfa, alfalfa, potatoes and sugar beets.

The leaf blades and petioles used for plant analyses were obtained from recently matured leaves and represented approximately the same physiological age throughout the season. The method of Haddock and Blood (6, 2) was used as a basis for appraising cooking quality (mealiness) of tubers. The rating will be referred to as quality index.[3] Starch was estimated from specific gravity by a formula suggested by Prince et al. (17).

A modification of Thomas' (19) "foliar diagnosis" and a modification of Ulrich's (20) petiole analyses procedures were used to diagnose the influence of treatment on nutritional status of potato plants.

Standard chemical laboratory procedures were used in analyzing the plant tissue. Ulrich's (20) extraction procedure was used for determining soluble nutrients. Barton's (1) method was used in determining plant phosphorus. The flame photometer, direct intensity method, was used for potassium.

Throughout this paper, when the chemical composition of leaves or leaf blade tissue is referred to, it is always on the basis of total composition. When reference is made to leaf-petiole composition, it is based on a 2% acetic acid extract (1 gram of dried plant material to 100 ml. of solute).

As a part of a complex field crop rotation experiment, an attempt was made to study the influence of irrigation method, frequency and quantity of water applied on the yield and cooking quality of potato tubers. Also, the influence of various irrigation practices on the chemical composition of the potato plant was studied.

Results and Discussion

Yield

Data presented in Tables 1 and 2 show that while more water was required for the moist plots under furrow than under sprinkle irrigation in order to maintain similar soil moisture tensions in the root zone of potato plants, there was no significant yield advantage for either method of irrigation.

The data showing yield of tubers under eight soil moisture conditions in Tables 1 and 2 represent means of 32 plots. These data indicate that, irrespective of the method of irrigation used, yields were increased significantly between irrigation treatments W_1 and W_3, W_2 and W_3, and between W_2 and W_4 for both seasons represented. No interaction between soil moisture condition and method of irrigation was indicated. The yield response to increasing frequency and quantity of irrigation water under the conditions of these experiments was good.

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[3]Quality Index is the mean weighted specific gravity of 50 randomly selected tubers. An average specific gravity of 1.080 is given a quality index of 80.

TABLE 1.—*Yield, quality index of tubers and chemical composition of plant tissue of Russet Burbank potatoes, 1952.*

Soil moisture condition	Yield cwt/A	Quality index	Starch fresh wt.* (Per cent)	No. irrig.	Water used (Inches)	Total comp. leaves 9/23/52 (Per cent)			Sol. comp. petioles 9/23/53 (Per cent)	
						N	P	K	NO_3-N	P
Sprinkle irrigation										
Dry — W_1	251	86.8	15.2	4	9	4.29	.192	1.82	0.95	.075
M-Dry — W_2	283	85.9	15.0	7	14	4.10	.179	1.84	0.68	.066
M-Moist — W_3	366	97.8	17.4	22	22	3.53	.165	2.08	0.36	.066
Moist — W_4	392	104.1	18.6	36	30	3.30	.161	2.04	0.16	.055
Furrow irrigation										
Dry — W_1	234	85.6	14.9	3	10	4.24	.197	1.60	1.08	.083
M-Dry — W_2	270	87.7	15.3	5	14	4.02	.185	2.00	0.58	.070
M-Moist — W_3	334	98.5	17.5	22	24	3.37	.158	1.98	0.23	.065
Moist — W_4	374	100.8	18.0	35	39	3.03	.168	2.04	0.13	.062
LSR @ .05**	53	5.1	0.9	..	..	0.28	.016	NS	.047	.016

*Calculated from specific gravity by formula: starch = 17.564 + 199.07 (sp. gr. — 1.09879).
**Duncan's Multiple Range Test.

TABLE 2.—*Yield and quality of tubers and chemical composition* of plant tissue of Russet Burbank potatoes, 1955.*

Soil moisture condition	Yield cwt/A	Quality index	Starch fresh wt. (Per cent)	Water used (Inches)	Total comp. leaves 9/8/55 (Per cent)			Sol. comp. petioles 9/8/55 (Per cent)		
					N	P	K	NO_3-N	P	K
Sprinkle irrigation										
Dry — W_1	175	77.5	13.33	3	4.48	.248	2.64	1.63	.075	7.32
M-Dry — W_2	250	78.6	13.55	10	4.29	.249	2.90	0.77	.077	6.73
M-Moist — W_3	333	85.8	14.97	18	4.00	.246	2.79	0.15	.086	7.86
Moist — W_4	328	89.7	15.75	20	3.89	.224	2.79	0.20	.073	7.01
Furrow irrigation										
Dry — W_1	188	74.3	12.69	5	4.58	.269	2.64	0.75	.090	8.68
M-Dry — W_2	238	81.8	14.18	14	4.09	.247	2.37	0.61	.071	7.16
M-Moist — W_3	324	87.9	15.40	23	3.59	.210	2.79	0.15	.065	6.39
Moist — W_4	350	91.6	16.13	37	3.15	.190	3.32	0.05	.061	6.53
LSR @ .05	37	4.2	1.27	..	0.37	.040	NS	0.49	NS	0.14

*Reference to composition of leaves is based on total composition in all tables. Chemical composition of petioles is based on 1:100 two % acetic acid extract in all tables.

Quality

Quality index was not affected significantly by method of irrigation (Tables 1 and 2). Within the range of soil moisture conditions studied, quality index was increased as quantity of irrigation water was increased. No interaction on quality index was observed between method of irrigation and soil moisture condition.

Starch

Starch content is an indication of maturity. It was highly correlated with good cooking quality (mealiness). Starch content of tubers was positively related to yield of tubers and quantity of irrigation water used. It was negatively associated with nitrogen concentration in leaf petioles (Tables 1 and 2).

Nutrient content of leaf petioles

The acetic acid soluble nitrate-nitrogen and phosphorus contents of potato petioles are shown in Tables 1 and 2. The marked decrease in nitrate-nitrogen content of petioles with increased quantities of irrigation water was related to increased yield and quality index.

The phosphorus content of petioles does not appear to be associated with soil moisture condition or yield in as consistent a manner as is nitrate-nitrogen. The 1952 petiole-phosphorus data shown in Table 1 indicate a significant decrease with increasing soil moisture and increasing yield. The 1955 petiole-phosphorus data in Table 2, particularly under furrow irrigation, show a similar trend.

Nutrient content of leaf blades

Total composition of potato leaf-blades from recently matured leaves show a significant decrease in nitrogen and phosphorus with increasing quantities of irrigation water and increasing yields (Tables 1 and 2). The potassium content of potato leaves tends to increase as irrigation water is increased, but significant differences were not achieved during either season.

If one were to assume that high yields of good quality potatoes were possible only when the crop was provided adequate mineral nutrition, it would be well to examine the nutritional status of the crop under the various irrigation regimes being studied here.

Kittam's leaf blade appraisal

It is known that different plant varieties vary in mineral composition when adequately nourished. Standards suggested by Kittams (12) for Western Washington are not limited to any particular variety. It is with some risk that standards set for unknown varieties in Western Washington are applied to the Russet Burbank variety in Utah. The critical levels or minimum concentrations of plant nutrients suggested by the Washington investigations are 6.0% nitrogen, 0.4% phosphorus, and 4.5% potassium in leaf blades of recently matured leaves 45 days after planting. If one compares those standards with the data in Tables 1 and 2, he must conclude that as the potato plants become more deficient in phosphorus and nitrogen, yields were increased. The potassium concentration in leaf blades is less exasperating when Washington standards are applied to them.

A similar risk to the one previously discussed is involved when one attempts to apply standards suggested in the Potash News Letter of December, 1958 for California to Utah Russet Burbank potatoes. California standards of nutrition for potatoes in late season hold the crop to be sufficiently nourished when acetic acid soluble nitrate-nitrogen in recently matured leaf petioles is above 0.50%, phosphorus above 0.10% and potassium above 6.0%. The potato plant is presumed to be deficient in the three primary nutrients when the petioles from recently matured leaves contain less than 0.30% nitrate-nitrogen, 0.05% phosphorus, and 4.0% potassium. Applying these standards to the data on chemical composition of potato petioles in Tables 1 and 2, one must again conclude that the nutritional status of these plants, especially with respect to nitrogen, deteriorated as yields increased.

The above conclusion to which one is driven by the use of "critical levels" with either leaf blades or petioles is contrary to the original assumption that high yields of good quality potatoes can be produced only under conditions of adequate nutrition. Is this a false assumption or is the use of "critical levels" an unsatisfactory basis on which to appraise nutritional status?

Nutrient balance in leaf blades important

The author has observed under a number of conditions that adequate nutrition is as much a matter of nutrient balance as concentration of available nutrients. Accordingly a modification of the method of Thomas (19) was applied to the data in Tables 1 and 2. These analyses are shown in Tables 3, 4, and 5. Instead of using Thomas' "quantity factor" ($N + P_2O_5 + K_2O$) expressed as the sum of the percentages of these nutrients in leaf blades) the author has substituted "quantity factor" ($N + P + K$ expressed as the sum of the milliequivalents per 100 grams of plant material). "Quantity factor" is an expression of the percentage which each nutrient element bears to the total ($N + P + K$) calculated on a milligram equivalent basis. Thomas' terms "quantity factor" and "quality factor" have been retained for convenience in referring to the two different types of analyses.

When the data in Tables 1 and 2 are analyzed according to this modification of Thomas' "foliar diagnosis", it is observed that the "quantity factor" is negatively related to yield (see Tables 3 and 4). While this is somewhat disconcerting, it is nevertheless consistent under furrow and sprinkle irrigation and at all levels of water application. As yields increase, these quantity values move away from Thomas' optimum value of 373 shown on the last line of Tables 3 and 4 for comparison. One exception to this is the quantity factor data for sprinkle irrigation in Table 4. An explanation for this general failure of quantity factor and yield to be positively related will be offered subsequently.

The analysis by means of "quality factor" is revealing. As the proportion of nitrogen in the leaf-blade was lowered from 80 to 75% in 1952 (Table 3) and from 78 to 69% in 1955 (Table 4), the yield and quality of potato tubers was increased significantly. It will be observed that these values were moving in the direction of Thomas' optimum of 62.7. The phosphorus values appear to be near Thomas' optimum. The

potassium values are much lower than Thomas' optimum of 32.2. However, as these values move in the direction of Thomas' optimum, yield and quality of tubers increase accordingly. The author is not proposing Thomas' optimum as an ideal. The ideal for Utah Russet Burbank potatoes may be higher or lower than Thomas' optimum, but it can serve as a tentative goal.

An explanation can now be offered for the negative relation between "quantity factor" and yield. As the nutrient composition of the potato leaf is brought into proper balance by increasing frequency and quantity of irrigation water, the yield of tubers is stimulated. It is the author's suggestion that potato yields are improved by the better balance of nutrients in the plant with increasing frequency of application and increasing quantity of irrigation water, in spite of the decrease in total nutrient uptake (quantity factor). The milliequivalents of nitrogen in the leaf blade are lowered faster than the milliequivalents of potassium are increased by more moist irrigation regimes. It appears possible that if the potassium concentration could be increased in the potato leaf to give a N : K ratio of approximately 2.00 that the "quantity factor" would simultaneously approximate Thomas' 373 with a further increase in yield of tubers.

N:K ratio in leaf blades a sensitive indicator of nutrient status

Since the better nutrient balance of the potato plant is brought about by a relative increase in potassium and a relative decrease in nitrogen, the essential relationship is the change in the N:K ratio in the plant. This relationship with increasing yield and quality is shown in the last column of Table 3. This appears to be a more sensitive indicator of proper balance than does "quality factor". If phosphorus were a varying quantity, it would not be detected in the N:K ratio values. It would appear that an ideal N:K ratio is approximately 2.00. Further study is needed to fix this value more precisely. It may vary with climatic conditions.

The data in Tables 4 and 5 are obtained by applying "quantity factors" to the data in Table 2. The results support the discussion pertaining to Table 3 and are provided here to show that results from different seasons are similar and also as a basis of comparing leaf blade analysis with leaf petiole analysis from the same plants in the same year.

Nutrient balance in leaf petioles

The data in Table 5 are obtained from the petiole analysis of Table 2. Since this is a different analysis of "foliar diagnosis" from that proposed by Thomas, it warrants a brief discussion.

The combined milliequivalents per 100 grams of plant material of soluble nitrate-nitrogen, phosphorus, and potassium in potato petioles are approximately half the total concentration of these nutrients in the leaf blade. Furthermore, they are present in different proportions in the petiole than in the blade. Nevertheless, it appears that quantity factors, quality factors, and N:K ratios could easily be established for this tissue, and would serve a useful purpose in appraising the nutritional status of the potato plant. As a tentative set of values for quality factors, it appears that nitrate-nitrogen should be less than 5, phosphorus about 3.5, and potassium about 91.5 in relatively mature or late season potato plants. The

N:K ratio for soluble constituents in the potato petiole late in the season should be about .05. Admittedly the acetic acid extract of potato petioles would fluctuate considerably throughout the season. Further study needs to be given to the desirable balance of nutrients found in extracts of potato leaf petioles before rigid standards are established for season and climate.

TABLE 3.—*Yield and nutritional status of Russet Burbank potatoes as affected by method of irrigation and soil moisture condition, 1952.*

Leaves

Soil moisture condition	Yield cwt/A	Quantity factor* Meq./100 g.	Quality factor**			$\frac{N}{K}$ Ratio Meq./100 g.
			N	P	K	
Sprinkle irrigation						
Dry — W_1	251	371	82.4	5.02	12.6	6.92
M-Dry — W_2	283	357	81.9	5.85	13.2	6.49
M-Moist — W_3	366	321	78.7	4.98	16.4	5.34
Moist — W_4	392	306	77.2	5.85	17.0	4.83
Furrow irrigation						
Dry — W_1	234	363	83.3	5.23	11.5	7.74
M-Dry — W_2	270	356	80.6	5.05	14.4	6.08
M-Moist — W_3	334	30[illegible]	78.7	4.98	16.4	5.40
Moist — W_4	374	287	75.4	6.37	18.2	4.49
LSR @ .05	53	27	3.3	0.80	3.1	1.36
Thomas's optimum Russet Rural 8/23	196	373	62.7	5.08	32.2	1.95

*Quantity Factor is sum of N + P + K expressed as milliequivalents per 100 grams of plant material.

**Quality Factor is the percentage that each nutrient element (N) is of the total N + P + K, calculated from a milligram equivalent basis.

Nutritional status of potato plants from various areas

The data presented in Table 6 are obtained from published reports of potato leaf analysis. Lundegardh (15) reports that the three varieties for which analyses are given in Table 6 were grown on mull-rich sandy soil, but no yield data are given. The dates for beginning of flower indicate early, medium, and late maturing varieties. Yet, the quantity factors and quality factors as well as the N:K ratios are remarkably similar. These values are similar to Thomas' values for high yielding plants. The data calculated from Kittams' (12) critical values for early season plants are at variance with Lundegardh's and Thomas' data. An explanation for the variation in Haddock's and Thomas' data has been given previously. The similarity of Lundegardh's and Thomas' data suggest that there may be factors other than variety and climate which account for a wide variation in quantity and quality factors.

TABLE 4.—*Yield and nutritional status of Russet Burbank potatoes as affected by method of irrigation and soil moisture condition, 9/8/55.*

Leaves

Soil moisture condition	Yield cwt/A	Quantity factor	Quality factor			*N/K Ratio
			N	P	K	
Sprinkle irrigation						
Dry — W_1	175	411	78.2	5.84	16.0	5.28
M-Dry — W_2	250	404	75.9	5.94	18.2	4.26
M-Moist — W_3	333	405	70.6	5.88	23.5	2.99
Moist — W_4	328	371	75.0	5.86	19.2	3.84
Furrow irrigation						
Dry — W_1	188	421	77.8	6.19	16.0	4.95
M-Dry — W_2	238	377	77.5	6.36	16.1	4.87
M-Moist — W_3	324	348	73.7	5.82	20.5	3.63
Moist — W_4	350	328	69.0	5.68	25.3	2.50
LSR @ .05	37	32	4.0	0.48	4.1	0.98
Thomas's optimum	197	373	62.7	5.08	32.2	1.95

*N:K ratio is expressed on a milligram equivalent basis in all tables.

TABLE 5.—*Yield and nutritional status of Russet Burbank potatoes as affected by method of irrigation and soil moisture condition, 9/8/55.*

Petioles

Soil moisture condition	Yield cwt/A	Quantity factor	Quality factor			N/K Ratio
			N	P	K	
Sprinkle irrigation						
Dry — W_1	175	311	37.1	2.35	60.6	0.621
M-Dry — W_2	250	235	23.5	3.20	73.4	0.321
M-Moist — W_3	333	220	4.9	3.77	91.4	0.054
Moist — W_4	328	201	7.0	3.58	89.4	0.078
Furrow irrigation						
Dry — W_1	188	284	18.60	3.09	78.4	0.252
M-Dry — W_2	238	235	18.68	3.03	78.4	0.246
M-Moist — W_3	324	180	5.71	3.50	90.8	0.064
Moist — W_4	350	177	2.14	3.32	94.5	0.023
LSR @ .05	37	33	8.40	0.42	5.1	.087

TABLE 6.—*Nutritional status of potato plants from various areas expressed on basis of quantity and quality factors.*

Leaves

Source	Stage of growth	Sampling date	Yield cwt/A	Quantity factor Meq/100g.	Quality factor			N/K Ratio
					N	P	K	
Lundegardh* — Sweden								
Early Puritan	Beg. flowers	7/16	..	450	61.5	8.46	30.00	2.05
Early Puritan	Withered	8/28	..	331	60.7	6.98	32.00	1.84
Magnum Bonum	Beg. flowers	7/31	..	431	55.7	8.14	36.20	1.54
Magnum Bonum	Withered	7/28	..	361	59.1	7.40	33.50	1.76
Gloria	Beg. flowers	8/7	..	450	55.1	7.33	37.60	1.47
Gloria	Full flower	8/28	..	423	58.6	7.87	33.60	1.75
Thomas* — Penn								
Russet Rural high yield	Mature	8/24	196	373	62.7	5.08	32.20	1.95
Russet Rural low yield	Mature	8/24	150	304	66.8	5.83	27.41	2.43
Kittams* — Wash.	Before flowers	8-10" High	..	582	73.6	6.69	19.69	3.75
Haddock — Utah								
Russet Burbank high yield	Mature	9/32	392	306	77.2	5.85	17.02	4.83
Russet Burbank low yield	Mature	9/32	234	363	83.3	5.23	11.45	7.74

*See literature citations by authors for reference to chemical composition.

Summary and Conclusions

Yield and quality (mealiness) of Russet Burbank potatoes are markedly increased by increasing the frequency and quantity of irrigation water. No advantage in yield or quality of tubers was observed for either sprinkle or furrow irrigation when soil moisture tensions in the root zone were comparable.

The use of critical levels as a basis for appraising the nutrient status of potatoes under some conditions appears unsatisfactory.

Conclusions favoring the use of a modification of Thomas' "quantity factor" and "quality factors" over the use of "critical levels" are based on the following three assumptions: (1) that concentrations of macro-nutrients (N, P and K) below the "critical levels" should adversely affect yield and possibly quality of potato tubers, (2) that high yields of potato tubers are possible only when potato plants are well-nourished and (3) that proper balance of macro-nutrients in plant tissue (N, P and K) is more important in the production of high yields of tubers than is the total concentration of these nutrients in leaf blades individually or collectively.

The application of a modification of Thomas' quantity factor and quality factor to data on the chemical composition of potato leaf-blades and leaf-petioles indicates that the proper balance of the principal nutrient elements is a critical factor in the production of high yields of potatoes. It would seem wise to determine the range in quantity factor and quality factors suitable to the production of high yields of the important potato varieties under the climatic conditions where they are to be grown.

Under conditions where phosphorus nutrition is not a controlling factor, the N:K ratio sensitively indicates nitrogen and potassium nutritional status.

The principle of foliar diagnosis, when applied to soluble constituents extracted from potato leaf-petioles, promises to be a useful basis for appraising the nutrient status of potato plants.

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NET NECROSIS ASSOCIATED WITH PRIMARY AND SECONDARY INFECTION OF LEAFROLL VIRUS IN RUSSET BURBANK[1]

JAMES W. GUTHRIE[2]

Leafroll virus induced phloem necrosis of *Solanum tuberosum* L. tubers has been known for many years (13, 14). In 1921 Schultz and Folsom (17) and Gilbert (3) in 1928 presented evidence that net necrosis was produced in tubers only when healthy vines became infected with the virus. Since then some investigators have used this reaction for diagnosis (16).

Tuber necroses of a net type due to causes other than potato leafroll virus infection are known. The necrotic net pattern has been reported to be induced by insects (9, 15) by herbicides, (10) and by low temperatures (19). I have also observed this net pattern associated with tubers infected with *Verticillium albo-atrum* R. and B. and*Fusarium solani* (Mart. Appl. and Wr. *v. cumartii* Carp.) Wr. However, as Davison (1) stated, tubers with virus induced net necrosis when planted will produce a plant with leafroll virus disease symptoms. All others will not.

Primary, or current-season, symptoms usually appear after midseason, first on the upper leaves, whereas secondary or seed-borne symptoms appear soon after the plant produces a few well developed leaves and symptoms occur first on the lowest leaves. Tubers exhibiting net necrosis give rise to leafroll infected plants. That net necrosis develops in tubers only as the result of a leafroll virus infection of a healthy vine has been the contention of numerous workers (17, 3, 19).

Except for my earlier report (4) it has not been previously demonstrated that net necrosis does occur in tubers produced on plants exhibiting symptoms of secondary infection. The objective of this paper is to report that net necrosis is not only a symptom of primary infection, but will also develop as a symptom of secondary infection.

MATERIALS AND METHODS

During the period of 1957-1959, tubers from plants known to have secondary infection were collected from 15 counties in Idaho. The plants selected were carefully lifted out of the soil with a shovel, the excess soil gently removed from the root zone and only those tubers attached to the stolons of that plant saved (Fig. 1). This was done to prevent accidental inclusion of tubers from adjoining plants that might have unseen primary leafroll infection. All samples so collected were stored. During the middle of January, the tubers were examined for the presence or absence of net necrosis by cutting a 3mm slice from the stem end, or point of stolon attachment. All tubers were rated on the basis of whether net necrosis were present, absent or questionable. A random sample of tubers from each annual collection was checked for the presence of culturable organisms by standard methods. All tubers were planted in field plots the following

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FIG. 1.—Typical expression of secondary symptoms of potato leafroll.

May and the resulting plants observed for symptoms of the leafroll disease.

During the summer of 1959, tubers were collected from plants inoculated with leafroll virus by infested aphids (*Myzus persicae* Sulz) at weekly intervals during June 10 to September 3. The aphids were cultured on leafroll diseased Russet Burbank variety potato plants. At each inoculation date, 10 infested aphids were placed in a special leaf cage (7), moved to the plots and attached to the leaf of a healthy Russet Burbank plant. Fifteen cages were charged and 15 new plants inoculated on each date. The tubers were harvested, stored and in January, 1960, they were inspected for net necrosis symptoms.

Caged and uncaged healthy plants were used as checks. Tubers were also collected from plants infected with the virus or virus complex from crinkle mosaic (potato virus X and A), rugose mosaic (potato virus X and Y) and calico (a strain of alfalfa mosaic virus).

TABLE 1.—*Net necrosis in Russet Burbank potato tubers obtained from plants with seed-borne leafroll virus infection.*

Year	Total tubers	Without net necrosis		With net necrosis	
		Number	Per cent	Number	Per cent
1957	392	214	55	178	45
1958	283	202	71	81	29
1959	253	124	49	129	51
Total	928	540		388	
Average			58		42

TABLE 2.—*Net necrosis in tubers from plants inoculated at intervals during the 1959 growing season.*

Inoculation date	Number of tubers	Number with net necrosis	Per cent
June 10	34	2	5.9
June 17	98	4	4.1
July 2	144	14	9.7
July 9	148	31	20.9
July 16	115	31	26.9
July 23	118	15	12.7
July 30	102	7	6.8
Aug. 4	146	27	18.5
Aug. 11	172	8	4.6
Aug. 16	154	12	7.8
Aug. 29	73	1	1.3
Sept. 3	98	0	0.0
Check-Uncaged	267	6	2.2
Caged check	206	0	0.0

RESULTS

The results are summarized in Table 1 and 2. The per cent of net necrosis in tubers from plants with secondary infection varied from year to year. Those tubers obtained from plants exhibiting seceondary leafroll virus symptoms that did develop net necrosis (Fig. 2) when planted produced a plant with typical secondary symptoms.

Tubers from plants infected with virus diseases other than leafroll did not contain the net necrosis symptoms, and when planted all gave rise to plants infected with their corresponding diseases.

Uninoculated plants grown in rows adjacent to the seed-borne infected plants or to the inoculated plants only rarely produced tubers with net necrosis symptoms. Plants grown under aphid-tight field cages yielded necrosis-free tubers, which when replanted, produced healthy plants.

The data illustrated in Table 2 show that the per cent of tubers which developed net necrosis from current season or primary infection was quite low in comparison with tubers from plants with secondary infection (Table 1).

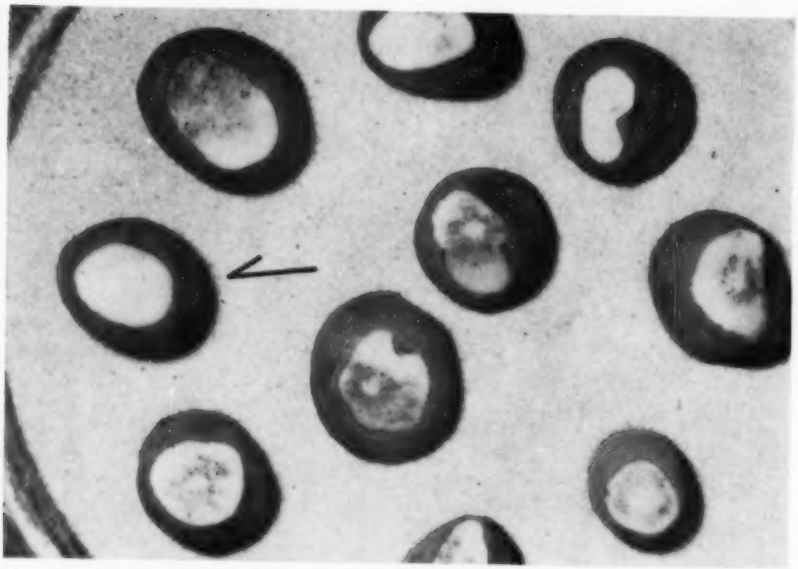

FIG. 2.—Net necrosis in tubers from seed-borne infected plants. The arrow indicates a tuber from an uninfected plant.

The tubers sampled for the presence of culturable organisms yielded various fungous species predominantly *Fusarium* sp. and *Verticillium albo-atrum*. The latter was obtained in approximately 16% of the tubers, which agrees with a previous report (6).

All tubers obtained from plants with seed-borne infection produced leafroll virus disease symptoms regardless of the presence or absence of net necrosis. This was ont entirely true with tubers from plants resulting from current season infection.

The degree of severity of necrosis varied from that of general netting over the major portions of the cut surface to a few necrotic strands (Fig. 2). Water-soaked tissue usually accompanied the necrotic net.

DISCUSSION AND SUMMARY

The absence of reports in the literature on the occurrence of net necrosis in tubers from secondary infection may indicate that it is a condition peculiar to Idaho and the Russet Burbank variety. The early, dwarf symptom of bacterial ring rot (5) has apparently enjoyed this same notoriety. The climatic conditions of Idaho are considerably different from those of the Midwest, East or even of the Pacific coast. This may account for such major variation in symptom expression.

Various techniques for leafroll virus diagnosis have been developed such as ultraviolet light detection (11) branch-trace necrosis (12) phloroglucinol tests (20) phloem necrosis (18) and indicator plants (8). None of these have been found useful in Idaho for practical purposes. At one time,

growers would bring a sample of tubers (not certified) to the Idaho Branch Experiment Station at Aberdeen for diagnosis of leafroll based on the presence of net necrosis. As a result of the present research, this service has been discontinued since the data show that leafroll can be present in tubers without net necrosis.

A number of workers have stated that net necrosis is a direct result of initial or current season infection by the leafroll virus (2, 19). The results reported herein do not support this view. Since net necrosis has been shown to occur in tubers from plants infected during a current season or plants resulting from a virus infected seed piece, and since leafroll virus infected plants can develop from tubers without net necrosis, and since not all tubers with net necrosis give rise to plants with leafroll virus symptoms: therefore the net necrosis symptoms cannot be used as a valid diagnostic characteristic of the potato leafroll virus in Idaho.

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THE IMPORTANCE OF POTATO VIRUS X[1]

JAMES MUNRO[2]

Although it is generally accepted that potato viruses are of serious economic importance when they cause obvious systemic diseases in commercial varieties, there has not been such a ready acceptance that barely perceptible foliage diseases from similar causes can also cause economic loss. Potato virus X is the most ubiquitous of the potato viruses and certainly the most insidious. Yet to many who are intimately concerned with potato culture, it is still a pathogen of doubtful importance because its effect upon a growing crop is not so obvious as that caused by potato virus Y or the leaf roll virus. We associate virus X with diseases that are barely perceptible and not worthy of control, and yet it is the one potato virus that can be most easily controlled by specific breeding.

It has been shown that virus-X infections that do not cause apparent diseases may still reduce the total weight of the crop (15, 18, 19, 20). In fact, reduction caused by symptomless infections of potato virus X was sufficient to initiate virus-X-free certification schemes in many countries (1, 14, 16, 19, 20). But despite these experiences in some countries there is general belief in others that loss in weight of crop can only be detected when plants show definite symptoms of disease (5, 6). Results on work with stocks free from virus X and stocks infected with symptomless strains of this virus did not show appreciable differences (2). This similarity in weight of crop may have been due to intensive selection within commercial stocks for local environment (2, 14, 15). Variations within varieties that affect foliage type and tuber yield are common, and lines infected with virus X can be selected to outyield other lines that are free from the virus (1). Experience has shown that with certain varieties it is almost as difficult to maintain stocks true to a type as it is to maintain them virus-free (14). The decrease in yield caused by variations within a variety can be similar to that caused by a virus disease. But when it cannot be clearly shown that reduced yield was due to a single cause, a grower is usually not interested. Even if slight differences due to virus infection could be detected, they would receive scant attention when there are wide fluctuations in prices paid to potato growers from year to year.

Although assessment of virus disease for seed certification is made by interpreting visible symptoms in a growing crop, intensities of the mosaics caused by virus X may vary during a growing season. Similarly, plants growing from the same source of infected stocks may show symptoms in one area and not in another. This is probably why 23 of the 26 certification schemes in operation in North America do not include simple mosaic in certification requirements.

STRAINS

Single strains of virus X are rarely found in the field as natural infectors. In fact, it is doubtful whether a truly single strain can be obtained by methods presently used. Under some conditions isolations and re-

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isolations by dilutions and local lesions that eventually are considered to be single strains may show themselves to be strain mixtures. Different potato seedlings may select different infective portions from an isolate that is being used as inoculum of a presumed single strain (11). Inoculations to *Datura stramonium* v. *tatula* with virulent strain may cause mild symptoms after passage through a succession of plants; and similarly mild strains may cause severe symptoms.

Field observations

Surveys of areas where table stock is grown from seed brought in at intervals of several years have revealed that there was a sharp increase each year in the number of plants with severe mosaic. Symptoms indicated that diseases were probably caused by either of the aphid-borne viruses A or Y, and virus X. However, in most cases tests showed that severe symptoms were caused by a dominance of severe strains of virus X alone (4). The varieties observed, Green Mountain and Netted Gem, are known to have been infected with virus X for many years.

In these surveys, cases of severe mosaic in single stems of otherwise healthy-looking plants were relatively easy to find (Fig. 1). Inoculations from symptomless parts of such plants usually caused mild non-necrotic symptoms of virus X on *D. stramonium* v. *tatula*. Inoculations from leaves on the severely diseased stems caused distortion and necroses of the same indicator plant (Fig. 2). Changes of this kind were first observed as severe mosaic in one compound leaf on a stem. An immediate test on D *stramonium* v.*tatula* plants indicated that a severe isolate of virus X dominated this severely diseased leaf, and a mild one dominated the rest of the plant. This severe disease then developed progressively from leaflet to leaflet in each of the remaining leaves on that stem (Fig. 3). Within three weeks of the first observation on the single leaf the whole plant was dominated by the severe strain, and symptom development had been followed from leaflet to leaflet within each leaf, from leaf to leaf on each stem, and from stem to stem.

Tubers were harvested from the foregoing plants and planted in the following spring. They were cut and planted to produce four plants from each tuber, and the shoots were observed as each plant came above ground. In most cases, one, two, or three plants from each parent tuber showed severe mosaic from the earliest stage of growth. Plants produced by each of the other parent tubers were either entirely symptomless or showed severe mosaic in all parts of the plant. All plants were tested and found to be infected with virus X alone.

Though movement of severe-strain virus particles to and within the tubers of these plants was comparable to movement in foliage, severe strain dominance was not always accomplished before the tubers were harvested and stored. According to MacKinnon and Munro (12), little movement of virus X takes place in potato tubers during storage.

These changes from symptomless infection to severe diseases are usually assumed to be caused by strain mutations. But although there may be a high frequency rate of mutation in potato mosaic viruses, it does not necessarily mean that strain mutation is always the cause. Severe mosaic that appears only in one stem of a field plant seems to arise when the weather has been variable. Delay in growth has been followed by a

FIG. 1.—Severe mosaic of single stem in an otherwise symptomless plant.

surge of growth and consequent sudden mass increase of virus particles. Under these conditions mutations may arise, but strain dominance may also change and the mild strains that formerly dominated and controlled the symptoms may be dominated in turn.

Under these unstable conditions, then, the principle of cross-protection does not hold. But even though this may not be commonly known, the doubt with which its practical value has been handled suggests that it is suspect. This attitude together with the practice of raising seed potatoes free from virus X in Holland, Germany, South Africa and Scotland indicates a tacit acceptance that cross-protection is unreliable.

CONTROL

Some strains of virus X tend to cause relatively severe diseases in most potato varieties, and others cause relatively mild diseases in the same varieties. Other seedlings and varieties become infected by isolates from within the mixture of strains that are contained in natural inocula. Some select strains that cause a mild disease, some select strains that cause a severe disease, and others appear to accept the complex (11). It has also been shown that some strains, selected for use in protective inoculations, do not infect certain seedlings. The same seedlings, however, become readily infected when the inoculum contains other strains. Such characteristics are found in seedlings from specific crosses (11).

Varietal resistance

Despite the tendency of some seedlings to be selective in acceptance of strains of virus X, potato plants have an overall inherent degree of resistance or susceptibility to the virus. A seedling therefore, may be assessed according to the ease or difficulty of becoming infected after inoculation, and by the consequent reaction after infection. It may be

FIG. 2.—*Datura stramonium* v. tatula: left, inoculated from symptomless stems, right, inoculated from stem with severe mosaic.

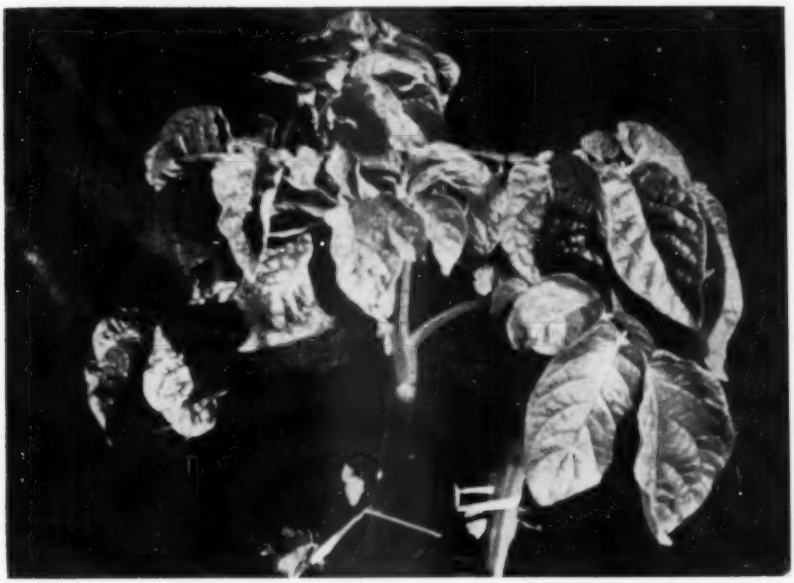

FIG. 3.—Severe mosaic developing from leaf to leaf in potato plant.

susceptible or resistant to infection, and tolerant or intolerant when infected. This of course excepts seedlings selected for immunity to this virus obtained in progeny when one of the parents is U.S.D.A. seedling 41956 or one of its derivatives.

The terms susceptible and resistant to infection relate to the same phenomenon. They refer to the ease or difficulty of virus entry and movement within a plant after natural inoculation.

Tolerance and intolerance are general terms that refer to the results of reaction between cell and virus and the consequent effect upon the plant as a whole. It may be that in each kind of cell there is a critical stage in the reaction between cell and virus or in virus multiplication. When this critical stage is reached there is cell breakdown indicated by mosaic, cell destruction indicated by necrotic streak, or both. In these cases the plants are considered to be intolerant to the causal virus or virus strain. If then the plant is tolerant, the critical stage is not reached, because of impeded multiplication or of a parasitism almost akin to symbiosis.

Although the relationship to resistance and tolerance cannot always be predetermined between plant and virus, there is a specificity of reaction of plant to virus strain, and of virus to cell type. Seasonal changes and other environmental effects also appear to hasten or retard development towards the critical stage.

Field resistance

When resistance to infection and intolerance when infected are combined in the same host, the plant is considered to be field-resistant. Katahdin is an example of a variety that has this kind of resistance to the potato-mosaic viruses. Such varieties are probably readily accepted by growers when field-resistance includes a number of pathogenic diseases. They are considered to be 'easy to grow'. However, diseases caused by strains of virus X can best be prevented by breeding for field-immunity (8) or for immunity (21).

Field immunity

One of the fundamental differences between Old World potato varieties is in the way they react when grafted with a scion infected with any one of the potato viruses X, A, B or C (Fig. 4). Some are killed with top necrosis whereas others develop nonnecrotic symptoms. If some leaves of a plant that reacts with top necrosis to a specific virus with this graft method are rubbed with inoculum of that virus, necrotic local lesions develop on the rubbed leaves. This reaction is an efficient form of immunity from the causal virus under natural conditions of infection, and varieties that react in this way are described as being field-immune (7). These reactions that distinguish varieties are due to simple genetic differences. Cadman (3) has shown that the necrotic reaction to virus X is controlled by the gene Nx, and that all varieties carrying this gene are field-immune to all strains of virus X except X_B and its variants. There is also a linkage between Nx and Na, the gene that operates similarly in response to potato virus A (10).

The top-necrotic reaction is important when it is a rarity in the field, and the expression field-immune is apt. But sometimes a natural infection is not localized to the inoculated leaves, and when this happens the plants are killed by a systemic necrotic disease. Tubers set by such plants may show necrotic lesions or areas (Fig. 5). Eyes become necrotic and many fail to sprout; those that do, give rise either to healthy plants or to plants that become necrotic and die before tubers are formed. The

FIG. 4.—Top necrosis of a seedling caused by virus-X-infected scion.

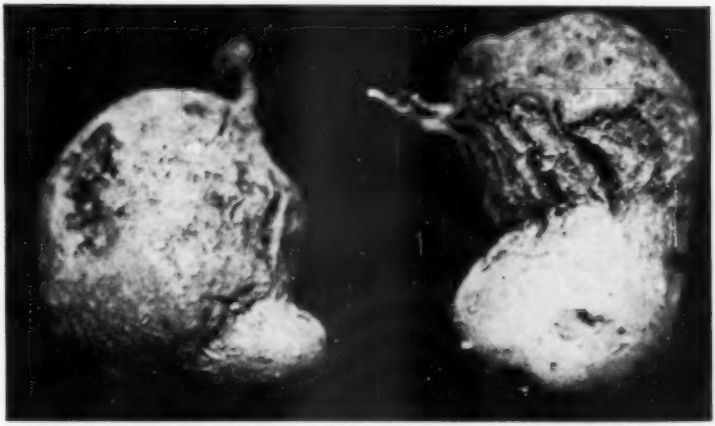

FIG. 5.—Tubers with necrotic lesions; harvested from plant destroyed by top necrosis.

frequency with which this occurs depends upon the variety and is probably due to extreme susceptibility to infection. According to Cockerham (10), varieties with a low degree of resistance, such as Arran Crest, show a greater proportion of necrotic systemic infections in the field than varieties with a high degree of resistance, such as King Edward. In any case, these infected plants are self eliminating in the field for the reasons outlined. .

Immunity

Although there is some doubt as to whether U.S.D.A. Seedling 41956 is immune or just extremely hypersensitive to virus X (17), there has been no report of this seedling or any of its selected derivatives being found in the field with an apparent disease caused by this virus. For all practical purposes, seedlings that react to inoculations with virus X in a similar way to that of U.S.D.A. Seedling 41956 are immune.

Growers' acceptance

A generalized field resistance to infection by potato disease pathogens seems to have been responsible for the popularity of certain varieties before specialized demands for processing became widespread. Certainly, immunity in the field to one or two viruses alone has not been and is not, sufficient to obtain growers' acceptance. Although the varieties Saco and Tawa are immune to virus X, they will, like Craig's Defiance which is field-immune to viruses X, A, B and C, rise or fall on other merits. In the production of new varieties not intended for specific purposes such as extreme earliness or processing, no one single quality is required any more than another. An attractive domestic variety of good culinary quality that produces commercial sized tubers fairly early may fail on the basis of extreme susceptibility to any one of the causes of major economic disease. Similarly, a variety with resistance to one or more specific pathogens may not be accepted because it lacks other major qualities demanded in a potato. There is no doubt that requirements in a potato variety include disease resistance, ease in culture and good cooking qualities.

Breeding of commercial varieties in West Germany has always been largely done by private breeders (13). This custom is to introduce a new variety that is superior in at least one respect, and equivalent in all others to the variety it will replace. Whether or not the replaced variety should go completely off the seed-potato market, may be a matter for debate; but the important thing seems to be that of progressively adding qualities to those already obtained. Unfortunately, many improvements are in degree and consequently not always apparent. Perhaps the greatest advantage of breeding for immunity or field-immunity to potato virus X is that, when obtained, it has been brought about by major genes and is a clearly recognized characteristic of the seedling.

The factors that determine the choice of breeding for immunity over field-immunity to potato virus X and vice versa are probably few. There are two in favor of field-immunity. Reference has already been made to the linkage between genes Nx and Na; the other is the greater possibility of obtaining earliness, good agronomic, and good culinary qualities. Cockerham (9) has shown that there is a wide range of possible parents with field immunity carrying many different combinations of other desirable qualities, whereas breeding for immunity is restricted to the use of U.S.D.A. Seedling 41956 and its derivatives as one parent. On the other hand the main possible weakness in field-immune seedlings is that of being extremely susceptible to the virus. When lethal necrosis of a potato plant caused by virus X is seen in the field for the first time, the observer is usually in doubt both as to its cause and its relative importance. But he need not be concerned, because the phenomenon is rare, it is self-eliminating, and it is abnormally conspicuous in relation to the actual number of such plants that could or would be in a growing crop.

Summary

Severe mosaics caused by potato virus X alone are commonly found in potato crops where new seed replacement is infrequent, and the varieties grown are wholly infected with the virus. These severe mosaics often arise in single stems of otherwise symptomless plants and spread rapidly through leaves of each stem until all foliage is showing severe symptoms. The rapid movement of a strain, newly arisen either by mutation or host selection, through parts of a plant already infected with that virus nullifies the principle of cross-protection.

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DISTRIBUTION OF VIRUS X IN CHRONICALLY INFECTED POTATO TUBERS[1]

J. P. MacKinnon[2]

Introduction

Previous work (1) showed that virus X did not move into all tubers of newly infected potato plants, nor into all eyes of infected tubers. Further, there was no evidence of any movement of virus within the tubers during storage. Little is known about the distribution or movement of virus X within tubers of a chronically infected variety either at harvest or during storage. I have tested parts from tubers of the Green Mountain variety after they were stored for different periods of time.

Materials and Methods

Each month from January, 1959, to December , 1960, 6 dormant tubers from the crop harvested the previous September were tested for virus X. Different tubers were used each month and samples of tissue (Approximately 250 mg.) were taken from location 1 to 6 (Fig. 1) of each tuber with a corkborer. In addition, each month from March to September, 1959, 6 tubers that had been allowed to sprout for 30 days, were also tested. Tissue samples were taken from the same locations and also similar sized samples were cut from locations 7 and 8 (Fig. 1). Each sample was crushed separately in a drop of water and rubbed over one leaf of *Gomphrena globosa* L., a local lesion host for virus X (5). One plant of *G. globosa* was used for the samples from each tuber. The number of lesions on each leaf was counted 7 days after inoculation. These have been shown (3) to bear a quantitative relationship to the concentration of virus X.

Results and Discussion

Virus X was recovered from all tubers but not always from every part. It was recovered each time from the base portion of the sprout (No. 7), and from over 90% of samples that included an eye (No. 6) or the tip of a sprout (No. 8). Percentage of infection in the parts which had no eyes, ranged from 58 at the center (No. 2) to 74 at the eye end (No. 4).

The concentration of virus X in each location was estimated month by month from the number of lesions the respective inocula produced on *G. globosa*. The most lesions resulted from inocula made from eyes or portions of sprouts, and the least from that made from the centers (Table 1). There was no evidence of change in virus concentration at any location either during storage or sprouting. The high concentration of virus in the sprouts apparently was due to multiplication in these parts, rather than a movement from other areas of the tubers.

Since locations 1, 2 and 3, were taken from the same core, it was thought that virus may have been pushed from the outside surface to

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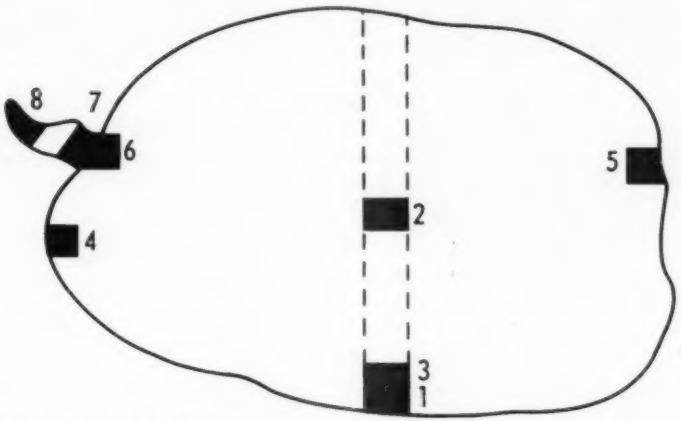

FIG. 1.—Diagrammatic drawing of a cross section of a Green Mountain tuber showing parts tested for virus X.

TABLE 1.—*Mean number of lesions on G. globosa by inocula from different locations in Green Mountain tubers.*

	Location[1]							
Tuber[2]	1	2	3	4	5	6	7	8
Dormant	1.2	0.5	0.8	1.2	2.6[3]	14.6	..	..
Sprouted	1.7	0.6	0.9	2.4[3]	0.9	14.9	36.7	26.6

[1]Tissue from each location as shown in Fig. 1 was inoculated to one leaf.
[2]Six tubers of each kind from the 1958 crop tested monthly for 7 months.
[3]Not significant.

the center by the corkborer. To ascertain that virus did occur at the center, 25 tubers were notched on the surface and broken into halves. Tissue was taken from a small center section of one half and tested as before. Virus X was recovered in this way from 22 of the 25 tubers.

It seemed possible that the number of lesions on *G. globosa* might be influenced by the season, but control tests each month with samples of frozen tuber juice showed no evidence of this. Lesions produced by the preserved juice varied from month to month, but there was no seasonal trend over the 2-year period. Samples of tuber juice frozen for 9 months showed no appreciable falling off in virus activity.

Prochal (2) found by testing eyes of recently infected tubers that virus moved from the stem to the eye end during storage. I found no evidence of such movement in chronically infected tubers when locations without eyes were tested. Also, Wilkinson (4) found a gradual decline in virus X from the outside to the center when inocula from several Green Mountain tubers were tested collectively. My results show little virus at the center, vascular ring, or surface of Green Mountain tubers where

the part tested did not include an eye. Virus was found most often and in highest concentration in parts including an eye or in portions of sprouts.

Summary

Virus X was detected in all Green Mountain tubers, but not always in every part. Most lesions on *Gomphrena globosa* resulted from inocula made from eyes or portions of sprouts, and virus was found most often in these parts. There was no evidence of movement of virus during storage or sprouting, but high virus concentrations in the sprouts apparently resulted from local multiplication. There was no seasonal influence on the number of lesions produced on *G. globosa*, nor was there any appreciable decline in active virus in tuber juice frozen for 9 months.

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ERRATA VOLUME 38

Page 246, line one, last paragraph *read* 17% instead of 18%.
Page 247. Table 1 column two *read* 234.1, 416.0, 320.8, 388.6; column three *read* 194.9, 335.8, 313.6, 332.5; column four *read* line one read 17.
Pages 313-314, by-line: *read* James C. Horton *for* August Kehr.
Page 375, *add* S. E. Sides to Machinery and Equipment Committee.

NEWS AND REVIEWS

SOUTHLAND FARMS[1]

DICK CONLEY

Continuous USDA inspection, hydrocooling, and extensive mechanization are three reasons why Southland Farms, Inc., Montgomery, Alabama, is currently ranked as one of the nation's most progressive fresh potato growing-packing-shipping organizations.

Southland Farms has been in the potato business since 1946. Presently the company grows and ships 2,000 acres of potatoes in Northern and Southern Alabama and in the Belle Glade and Homestead areas of Florida. However, the majority of production is concentrated in Baldwin County, on Alabama's Gulf Coast. Other operations are considered as supplemental, to lengthen the shipping season and spread the risks. The company ships from Belle Glade from mid-December through January, then shifts to Homestead for operations from mid-February through April. Baldwin County shipments begin in early May and continue through the middle of June. Final shipments come from the Sand Mountain area of Northern Alabama (near Chattanooga, Tenn.) throughout the month of July. All shipments are made under the "Gulf Beach" brand.

Southland's principal variety is the Red LaSoda, a potato well suited to southern growing conditions. This variety, according to Cole Brown, Southland Farms president, carries well and has good eye appeal; it is replacing the Pontiac as the area's major variety. For a white shipping potato, the company prefers Sebagos, which account for 20% of the total production, and are sold both as chipping and table potatoes.

BALDWIN PLANT

The pride of the Southland operation is the Foley packing plant in Baldwin County which was completely redesigned in 1960 at an approximate cost of $250,000 so as to increase hourly packing capacity from 36,000 to 80,000 pounds. This plant utilizes some of the latest methods of materials handling. It contains 20,000 square feet and has rail sidings for the simultaneous loading of 12 cars as well as separate dock space for six truck trailers.

Southland Farms grows all potatoes shipped under the "Gulf Beach" brand on company-operated farms. Growing operations are carefully supervised as a major key to the ultimate quality of the Southland's potatoes, not only to Cole Brown and other company personnel, but also by USDA inspectors as an integral part of the continuous inspection program. The same inspectors who will later be in the packing plant also examine the growing crop in each field for diseases or conditions that might affect carrying quality, with full authority to prohibit shipment of these potatoes under the continuous inspection shield.

Southland's Baldwin County harvesting operations are conducted with a mechanical two-row harvester that digs potatoes and conveys them

[1]Reprinted with permission from Produce Marketing, Vol. 4, No. 3.

directly into wooden field boxes holding about a bushel which, when filled, are stacked on a truck running alongside the harvester. "This system keeps the potatoes off the ground and provides rapid, economical field handling," says Brown. "Further, constant and prompt movement of potatoes is provided by our small fleet of trucks as they continually shuttle between this harvester and the packing plant," he adds.

As soon as these loaded trucks arrive at the Foley packing plant, they back into a large shaded dock and are promptly unloaded.

Packing Operations

The field boxes are conveyed to the wash tanks and the potatoes emptied into the four-foot-deep tanks for pre-soaking and partial washing. The potatoes are carried out of the tanks by roller conveyors, passing through a high pressure water sprayer as they leave which completes the washing operation.

The next step is through a sizing machine which removes small potatoes, or "creamers," from the fresh line. From here, the acceptable-sized potatoes are conveyed to the double deck hydrocooler.

Potatoes move through this 53-foot hydrocooler on two specially-designed horizontal escalator-type conveyor belts containing side vertical belts that combine to prevent any movement of individual potatoes within the hydrocooler. "By holding the potatoes immobile we eliminate the possibility of bruising during this cooling operation," says Brown.

While these two conveyor lines operate separately in the double deck hydrocooler, both are cooled by the same water which moves from top to bottom by gravity at a rate of 7500 gallons per minute. This water is held at 29-32 degrees, just high enough to prevent formation of ice, and contains 200 parts per million of chlorine, which serves as a decay inhibitor. The potatoes take approximately 22 minutes to pass through this variable speed hydrocooler, depending upon initial temperature, and leave with a pulp temperature of 48-53 F.

Each level of the hydrocooler feeds a separate packing line. Coming out of the hydrocooler, the potatoes are first carried across drying areas. Here, overhead fans and absorbent rollers combine to remove surface moisture. A second sizer removes "B" size potatoes, which are transferred to a separate packing line. At grading tables, experienced women sort out defective potatoes. A third sizing operation takes out the large potatoes from the "A" lines; the dividing point may be either 3 or 3½ inches, depending on consumer specifications. This sizer feeds two outlets, one for consumer-unit packages, the other for 50 and 100 pound burlap bags.

Bagging Machinery

Consumer-unit packaging is done on one of three Baker Weigh-O-Matic machines, one for each of the two grade "A" packaging lines, and one for the combined "B" line.

These "merry-go-round" Baker units receive and package potatoes in a continuouus mechanical cycle. Potatoes are fed into the machine's series of front filling stations which automatically fill the bags to a pre-set

weight. Packages used include five and ten pound polyethylene bags and ten and 25 pound paper open window bags.

After packaging, the bags are automatically conveyed to waiting refrigerated transportation. Total elapsed time following emergence from the hydrocooler until the bagged potatoes reach this refrigerated transportation is just five minutes.

During the 1960 season Southland Farms made news by being the first shipping-point potato packer in the country to package under continuous USDA inspection.

Under this program, from two to three USDA inspectors are on hand continuously during all plant operations, with free access to all phases of the operation and complete authority over all sanitation facilities. In addition, these inspectors make lot inspections of the potatoes after packaging.

Continuous Inspection

The resident inspector authorizes the display of the "Continuous Inspection" shield on potato packages meeting all specified requirements. By the same token, he denies use of the shield on all potatoes which fail to come up to grade or other requirements, although his constant observation of the packing line helps him to point out any deficiencies to supervisors for immediate corrective action.

"We feel that this continuous inspection shield has added real prestige to our 'Gulf Beach' brand, and has provided our customers with the assurance that they are purchasing the finest quality potatoes possible to pack," says Brown.

"Receiver response to our continuous inspection program has been completely favorable," he continuous. "Last year we shipped 493 carload equivalents under this program without a single rejection or complaint. Nearly every one of these cars, I might add, topped the market."

Southland Farms shipments are made to both wholesale and retail companies located in major Eastern and Midwestern markets, with occasional shipments further west.

"Our first year test with continuous inspection has proved one thing to us: That good quality purchases are most important in these buyers' minds than low-price purchases," Brown concludes.

Increase potato profits Treat seed pieces with Du Pont SEMESAN BEL®

Only "Semesan Bel" helps control all these diseases:

Bacterial ring rot	Seed-borne scab
Black leg	Fusarium
Rhizoctonia	Verticilium wilt

• **Improves your yield and profit**—Time and again in field tests, under actual growing conditions, seed pieces treated with "Semesan Bel" have given better yields than pieces treated with other disinfectants *or* protectants.

• **Gives better quality**—Watch your yield of No.1 potatoes rise when you plant seed pieces treated with "Semesan Bel"! And that's where you make your money!

"Semesan Bel" is easy to use. It mixes easily with water: you simply dip seed pieces into the solution, drain and let dry. No long soaking needed. One pound of "Semesan Bel" in 7½ gallons of water will treat 60 to 80 bushels (36 to 48 sacks) of seed. Get a supply of Du Pont "Semesan Bel" from your dealer and see for yourself.

On all chemicals follow labeling instructions and warnings carefully.

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